The Simulation Modeling Technology of Warehouse Logistics Processes in Distributed Computing Environment

I.V. Bychkov, G.A. Oparin, A.G. Feoktistov, V.G. Bogdanova, A.A. Pashinin

Matrosov Institute for System Dynamics and Control Theory of Siberian Branch of RAS, Lermontov str., 134, 664033, Irkutsk, Russia
idstu@icc.ru

Abstract. The problem of analysis of functional and organizational structure of logistics warehouse is considered in this article and a new technology for performing such analysis is offered. The technology is based on simulation modeling. In detail this technology includes methods and tools for development of simulation models, for creating problem-oriented services of the simulation modeling, for intelligent management of computing in a distributed environment. The aim of research is to develop and realize high-level methods and tools of formulating and solving non-traditional (for conventionally used warehouse management systems) tasks using problem-oriented knowledge. The example of methods and tools realization to automate the simulation modeling of the logistics warehouse is presented here. Experiments results for some tasks of the simulation modeling of the logistics warehouse are discussed.

Keywords: simulation modeling, warehouse logistics, distributed computing environment, service-oriented programming

1 Introduction

A mathematical modeling of technological processes plays important role in the research and optimization of enterprises. Currently, the enterprises, that are focused on an ultimate consumer and integrated in logistics chains, are most effective. The warehouse logistics, oriented to the management of material flows, makes the significant contribution to indicators of functioning of enterprises. The particular attention is paid to regional warehouses. This situation is due to the fact, that today the significant number of large Russian production companies and retailers are choosing an expansion of sales in regions as the main direction of their development. Therefore, enterprises sharply need high-quality large-scale warehouse logistics servicing.

Modern logistics warehouses are rather difficult economic systems oriented to the management of cargo traffic of the large capacity, including the distribution of goods, and, therefore, play important role in the economic sphere. In this regard, the most important tasks of warehouse management are the analysis and optimization of a functional and organizational structure as the exploited and designed logistics warehouses. The development trend of modern logistics warehouses is the constant improvement of technologies and communication systems, expanding the set of warehouse and logistics operations and it increases their level of complexity, the emergence of many alternatives to the adoption of logistics solutions.

One of the most effective approaches to an analysis of functioning of a logistics warehouse as a queuing system is simulation modeling [1]. Imitation modeling is a modern tool which simplifies the development and the optimization of warehouse operations. Simulating a warehouse implies developing a simulation program and testing it by executing experiments with different combinations of warehouse parameters. These experiments provide a low-cost method to determine the optimal parameter set for a warehouse.

A process of building a simulation program adequately reflects the system of study which is largely non-trivial task and requires from its developer the high mathematical and programming skills [2], especially when it comes to parallel or distributed program [3].Thus, there is a need for high-level tools to automate the process that will maximize the potential of high-performance computing and provide the building of complex technological chain: from formulating task to creating model, then to developing program and to carrying out experiment in a distributed computing environment.

In this paper the simulation modeling technology of warehouse logistics processes in a distributed computing environment is proposed. This technology includes methods and tools for developing simulation model, for creating services of simulation modeling, for intelligent management of computing in a distributed environment. The example of realization of methods and tools to automate simulation modeling of the logistics warehouse is presented. Experiment results for some tasks of the logistics warehouse simulation modeling are presented in this article.

2 Material and Information Flows Management in a Modern Logistics Warehouse

Warehouse performs logistics operations with material and information flows: transportation, loading/unloading, packaging, warehousing, packaging, cargo processing, collection of returnable waste, distribution, pricing and other operations. Fig. 1 shows the information and logical interconnections of some basic logistics operations in the warehouse. Material and information flows define the relations between the logistics operations. Management of material and information flows in modern logistics warehouse is carried out by the warehouse management system (WMS).

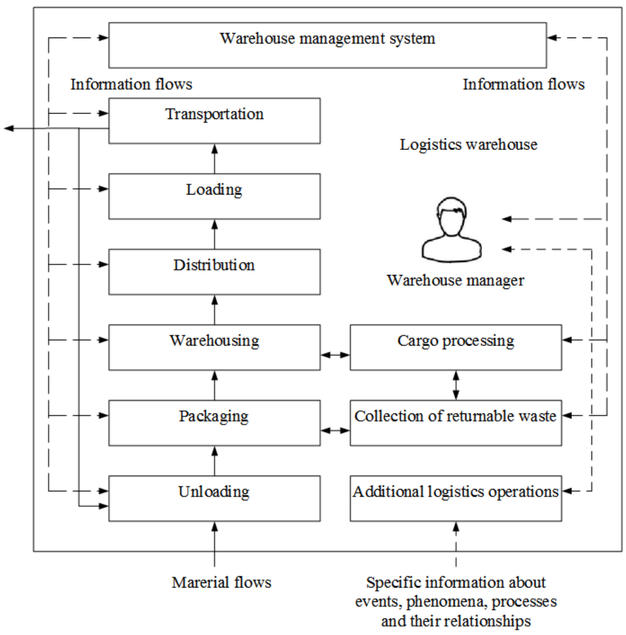

Fig. 1. Operations of logistics warehouse.

In Russia, WMS is presented with large range of software systems. They include such systems as 1C-Logistics: WMS [4], GESTORI Pro [5], Solvo.WMS [6] and others systems [7]. Such software systems include some modeling tools of warehouse processes. But they are usually highly specialized and not suitable for the simulation of many logistics processes encountered in the implementation of the joint operations of warehousing, transportation and trade. Systems for enterprise resource planning (ERP) [8], for example, the Oracle E-Business Suite [9], SAP ERP [10], Microsoft Dynamics AX [11] or Infor ERP LN (BAAN) [12], are powerful tools for management of enterprise processes, including the warehouse processes. However, such commercial systems are oriented mainly to the large enterprises. Generally these systems use analytical modeling techniques which do not take into account all details of additional logistics operations and do not analyze these details in dynamics, unlike the simulation modeling.

Moreover, in solving of practical tasks it is often necessary to implement additional logistics operations (Fig. 1) and to process specific information about events, phenomena, processes and their relationships that do not fit the model of problem. Additional logistics operations apply to information flows. For example, scheduling logistics operations, predicting equipment failures, transformation external constraints into internal constraints, allocation of resources for the implementation of logistics operations, an analysis of the operations implementation efficiency.

Thus, the aim of research is to develop and realize high-level methods and tools of formulating and solving non-traditional (for conventionally used WMS) tasks using specific problem-oriented knowledge. The main problem is the development the simulation modeling system with the service-oriented interface and technology of implementation to support the manager of the logistics warehouse in making decisions.

3 Simulation Modeling Technology of Warehouse Logistics Processes

The authors developed software to support the experimental simulation modeling. Simulation models are implemented in the language of General Purpose Simulation System (GPSS) [13]. This software includes the tools of developing simulation models on the base of templates for typical objects (modules) of the researched systems and tools to support the experimental simulation modeling with the developed models. The modular approach provides a number of important advantages. Firstly, it is the flexible modification and development of mathematical support and software of the basis for modeling the researched systems. The modification and development of mathematical support and software is carried out with the help of extension or replacement of modules of this basis by new modules, including the modules from the developed libraries of templates for objects of researched systems. Secondly, it is the rapid point implementation of additional capabilities of system processes modeling, not represented in the used WMS.

The considered software focuses firstly on PC-based clusters that are created on the base of computing resources of corporate, educational or scientific organizations. The clusters must function under the control of the local resource manager Condor [14]. This system has the following advantages. Firstly, the creation PC-based cluster is based on any available network that requires minimal cost and time; it operates under a variety of operating systems, including OS Windows; it is the open source of software.

The technology of simulation modeling with the help of the developed software and cluster under the control of the Condor includes a number of stages.

The stage of *experiment planning* includes: the determination of the runs number of the model before moving to operating mode and in operating mode; selection of the main factors and observable variables of the model; carrying out of the factorial analysis. Some specialized tools are realized in software for simulation modeling. These tools provide abilities to use unlimited number of factors and levels (unlike tools of GPSS World [15]), to implement the factorial analysis in parallel and to automate the processes of planning and execution of experiments.

The stage of *input data preparation* for experiment includes: selection GPSS-model, files with additional model fragments and files with variants of input data.

The stage of *specifying of job* for model run in distributed computing environment includes description of instructions set for computing system in terms of Condor. The job is a specification of the process of solving the problem, including information about the required computational resources, software, variants of the input/output data, quality criteria of the job execution, as well as other necessary information.

The stage of *job execution planning* includes the choice of nodes of distributed computing environment in which this job may be executed. The logical-and-probabilistic algorithm for multilevel scheduling of job flow with defined criteria (reliability, time and cost) of quality of their execution is used to the nodes choice. The planning process is carried out in four steps by a special system of program agents representing the cluster nodes. The planning process includes: forming of set of available nodes; specialization of formed set by way of removing of overloaded nodes (relative to the current average loading nodes, taking into account existing job queues) from this set; creating polyvariant plan of job execution in nodes; creating specialized plan, that satisfy the defined criteria of quality of job execution and current state of the computing environment, by way selection from polyvariant plan; allocation of cluster nodes for job execution in accordance with the specialized plan. The specialized plan is formed on the basis of economical regulation mechanism of demand and supply for computing resources [16].

The stage of *job execution* includes job run in allocated node of cluster and sending calculations results to the main node of cluster. In case of the node failure a new allocation of node for the job run is carried out.

The stage of *output data processing* includes reports collection and the extraction from the reports relevant data for further analysis.

The stage of *data analysis* includes the of multi-criteria selection problem solving parameters optimal values of the researched. The lexicographic and majority methods of choice are used to solve this problem. These methods are chosen for their ease of use by specialists of problem domain and program implementation as compared with other similar methods.

The all considered above stages are fully or partially automated and presented as a Grid-services. Now, there is a wide range of tools [19] for service creation. The technologies Web Services Resource Framework (WSRF) [18] and using of templates for interconnection with local resource managers of distributed computing environment are used in the paper. The system High-performance computing Service-oriented Multiagent System (HpcSoMaS) Framework, developed by authors, is used for service creation based on these technologies.

4 High-Performance Computing Service-Oriented Multiagent System Framework

This framework is designed for implementation the agent-based approach to automate the creation of software systems to solve large-scale scientific problems in a service-oriented Cluster Grid with computing nodes which can have complex hybrid structure.

With this approach, computing management is implemented with the help of the multiagent system (MAS) The organizational structure is shown in Figure 2. Coordination of agents is implemented with the help of general rules of group behavior. Agents operate in accordance with the specified roles and their rules of behavior in the virtual agents' community, which are defined for each role. The MAS includes agents of users, computing planning, monitoring and distributing the resources, classifying, specializing and running the jobs. The agents can coordinate their actions through cooperation or competition in different virtual communities arising in the MAS. In details this MAS is described in [16].

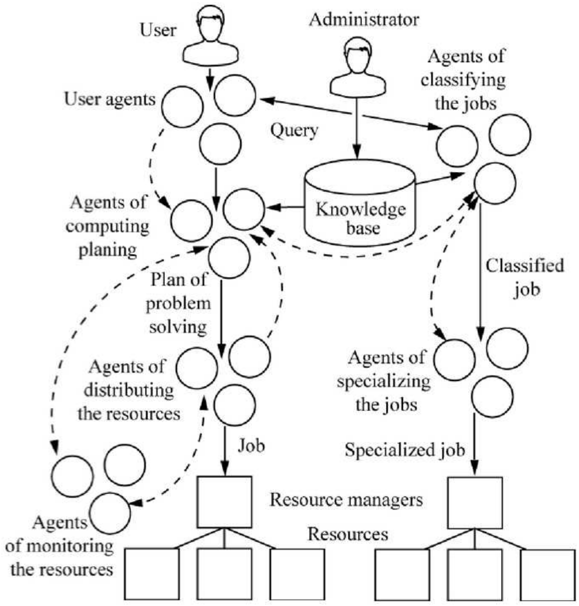

Fig. 2. The multiagent system structure.

Unlike some well-known scheduling systems, this toolkit provides the ability to management of distributed computing both at collective level and at problem-oriented software (application) level. The main functional and system features of the application level implemented in the form of services. Agents at the application level are implemented as services too. The user's requests to services of application are implemented into jobs for resource managers of environment nodes.

Additional tools for computing scheduling and resource management at application level represent a virtual community (VC) of agents created to organize parallel execution of user application in distributed computing environment. Main purpose of VC is to provide the choice of the least loaded resource (cluster) to execute a parallel application and the monitoring to send results to the user. VC agents include a user agent, scheduling and classifying agents, a manager-agent and dynamic set of local agents. First three agents are used to receive and classify user requests and problem solving plan composition. A task formed after cooperative agent actions are transferred to the manager-agent who distributes the task at local agents by cooperation with a resource monitoring agent. The manager-agent is also used for: partition task into subtasks; automatic restart of task running with new parameters; management; user task monitoring. Local agents are used to send tasks into a cluster resource management system.

Framework includes a set of system components (standard agents) to be controlled by developed agents and the library of standard classes for Java programs. This library supports implementation of software tools to manage the agents, information and message exchange between agents and other functions. Library of standard classes provides classes for all types of VC agents. Agents-managers are the main components in HpcSoMaS Framework. These agents produce most of the work on the distribution of tasks, selection of the best computing environment for a specific task, interaction with resource-manager of cluster, reallocation of tasks, and their decomposition.

Unlike other similar tools, such as [19],[20],[21], using HpcSoMas Framework agents may be presented in the form of services. The access to user application may also be issued in the form of services. Agents-managers are presented as rest-services. Agents-managers use the soap-services to perform different functions, depending of the configuration of the VC, and should have the ability to dynamically connect these services without recompiling.

This framework provides the possibility of building web services and interfaces for the conversion of users' requests to the VC in the combined flows of tasks and the distribution of these flows tasks in a computing environment. Therefore, in addition to the main library the HpcSoMaS Framework includes:

- the library for development of services based on REST and SOAP standarts;
- the ready-made services that implement system functions of VC agents basing on library classes and require for their use only configuration setting;
- tools for graphical design of services;
- the documentation, describing the format of service configuration file.

This framework was used for creating problem-oriented services of the simulation modeling service and VC of agents for intelligent management of computing in a distributed environment at the application level.

5 Experiments

Service-oriented system simulation provides the following features that are supported by HpcSoMas Framework:

- Web-service interface for generating and editing the list of observable parameters Observable Parameter List Edit (OPLE). This list then is used during the simulation.
- Web-interface for the user's request to simulations. Setting parameters for computing experiment: the input and output of the program, the list of observable output parameters.
- Parallel solution through multivariant calculations for different input parameters in a distributed computing environment.
- Information of the user about the completion of the solution. Integrating and visualization of the solution results.

Service simulation contains the following input parameters (Fig. 3):

- The model name.
- Number of model runs for transition to the operating mode.
- Number of model runs in the operating mode.
- List of variant of input data.
- A list of observable parameters. This list is generated by a web-interface of OPLE.
- Choose the method of analysis of statistics.

Some problems of warehouse logistics, solved with the help of cold-store Co Ltd вЂњIrkutsk KhladokombinatвЂќ using the researched technology, are given below. Co Ltd вЂњIrkutsk KhladokombinatвЂќ has the following characteristics: total storage volume 20000 t; 42 storages; several temperature regimes of storages; four floors and several freight elevators; ramps for road and rail transport; eight commodity groups; different categories of customers; many areas for office, back offices, garages, processing of goods.

Modeling of loading/unloading processes. The warehouse under study operates with input and output material flows, on base of both scheduled and random requests. The generated

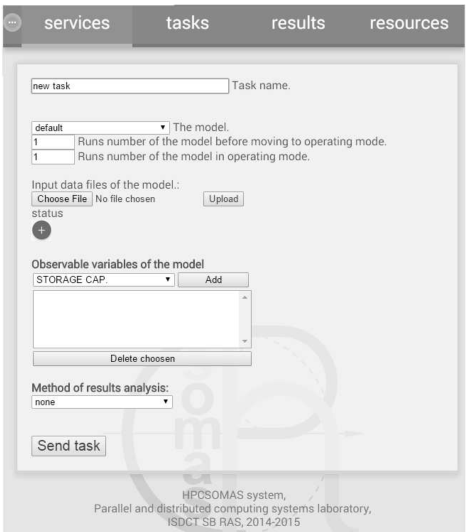

Fig. 3. Web-interface of the simulation service.

daily scheduled requests contain information about the time of arrival/departure of the goods, the servicing time of request, the volume of goods, and the required resources to carry out the logistics operations. The intensity of the random requests varies in different times. The processes of arrival/departure of the goods have different characteristics and correspond to the different probability distributions. For servicing applications using following technical and human resources: electric loaders, electric loader drivers, storekeepers, loaders, elevator operator, dispatchers and others resources.

The problem was to determine the optimal distribution of resources for logistics operation in loading/unloading processes. The specific features of this problem are availability of elevators and temperature regimes of storages. These features are usually not taken into account in WMS. The problem was solved by multivariate calculations with followed multi-criteria choice of variants of initial data (the optimal distribution of recourses).

The modeling results were used in the management divisions of the cold-store for following works: developing of method for forming of scheduled requests and accounting random requests; forming teams of electric loader drivers, storekeepers and loaders; scheduling of these teams work; planning of servicing and renewal of technical resources.

Modeling of customer servicing level. On the cold-store the loading/unloading processes are carried out for the road and rail transport of different carrying capacity. There are standards of the loading/unloading processes for the type of freight transport, type and category of cargo. Failure to comply with the standards entails penalties.

The problem was to determine the distribution of resources for the preferred customer servicing level [1] .

The problem was solved by multivariate calculations with followed choice of variants of initial data, corresponding to the values of the observable variables that satisfy the given constraints.

The modeling results were used in the management divisions of the cold-store for following works: developing and optimization of standards of loading/unloading processes; determining of categories of loyal customers.

The simulation models are designed in the system GPSS World. The simulation modeling was carried out on the cluster of 20 heterogeneous PCs (40 cores) and the cluster of 12 homogeneous PCs (24 cores). The both clusters are functioning under the control of the OS Windows and local resource manager Condor. In experiments the number of data variants for models ranged from 100 to 10000. One task for Condor was generated by agents for the one run of model. The one job was executed on a one core. Estimations of time spent on different stages of the experiment with one data variant for automated and non-automated simulation modeling are showed on Fig. 4.

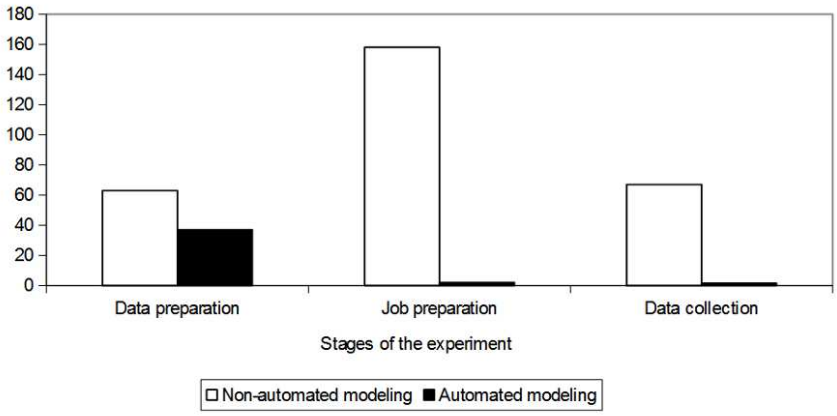

Fig. 4. Estimations of time spent on different stages of the experiment with one data variant.

Figure 5 illustrates the scalability of multivariant calculations in distributed computing environment (the acceleration of performance is near to linear) for tasks of simulation modeling of customer servicing level and loading/unloading process. On figure 5: T1 вЂ“ the time of task solving using one core, Tn вЂ“ the time of task solving using n core. The modeling of the developed service for simulation using the resources (over 3700 cores) of the supercomputer center at the IDSTU SB RAS showed similar results scalability.

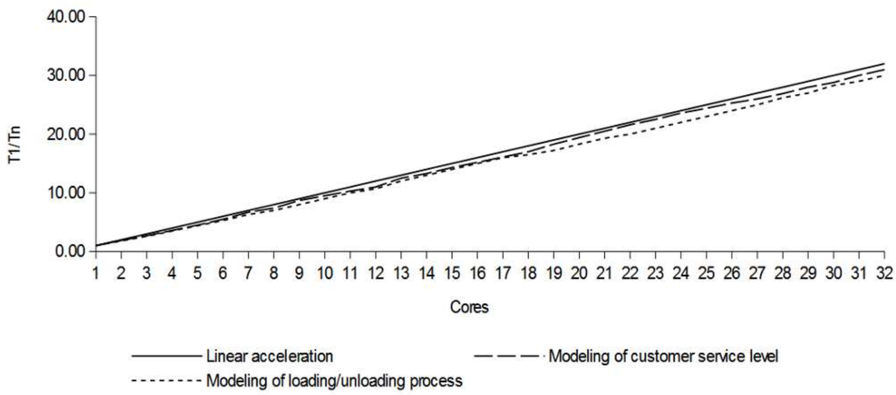

Fig. 5. Scalability of multivariant calculations in distributed computing envinronment.

Based on estimations, obtained in the process of solving practical problems and scalability of multivariant calculations in distributed computing environment, we can conclude about high efficiency of service for simulation.

6 Conclusions.

In this paper the some initial results of a study that focus simulation modeling of warehouse with non-typical logistics operations are showed. The automation of simulation modeling and the use of distributed computing have provided the rapid modeling results, needed for making management decisions. The principles of work, the technology of application, means and ways of implementing the above mentioned methods and tools are provides their widespread use to simulation modeling of complex systems in different spheres of human activity.

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